ART. I.—*On the Temperature of Solar Radiation, as Measured by the Black Bulb Thermometer.* By Mr. R. L. J. ELLERY, F. R. A. S., Government Astronomer, &c., President of the Royal Society of Victoria.

[Read 24th February, 1868.]

The temperature of solar radiation at the earth's surface, or as it is more commonly known, the "temperature in the sun," is now usually measured by means of a black bulb thermometer fully exposed to the sun's rays, the maximum temperature attained being marked by a self-registering index. These thermometers are now generally enclosed in an outer hermetically sealed tube, from which the air has been exhausted, the bulb of the thermometer itself being made of black glass. Such an instrument has been in use at the Melbourne Observatory for many years past, and the maximum temperature of solar radiation indicated by it has been assumed and published as the greatest heat in the sun.

In the "Philosophical Magazine" of March 1866, a letter from Professor Tyndall appeared, discussing the results of some observations of solar radiation made by Mr. Glaisher in one of his balloon ascents. The letter concludes by stating that "If these remarks be correct, or so far as they are correct, the indications of the black bulb thermometer, as at present constructed, are delusive, and especially so at great elevations." The remarks he refers to relate to the transparency of ordinary black glass to the invisible, or the greatest heat rays of the spectrum. From this letter we may conclude that Professor Tyndall's opinion stands thus :—

"That the black glass, of which black bulb thermometers are usually constructed, is not opaque to all the heat rays of the spectrum, and therefore these rays may pass through the glass of the bulb to the surface of the mercury, and be there reflected back into space without raising the temperature of the mercury, and that the loss from this cause will increase with the height of the thermometer above the earth's surface.

After reading this I determined to try some experiments in order to ascertain if the maximum heat in the sun's rays was obtained by our black bulb thermometer. I therefore placed another black bulb thermometer alongside, and in all

respects under the same conditions as the one usually registered, but the bulb of the second thermometer was covered with a coating of lamp-black and size, so as to present a dead black surface. These two thermometers read the same in the shade, and as ordinary thermometers were accurately intercomparable. It was immediately apparent, however, that the simple black glass thermometer did not indicate the true solar radiation, the coated bulb always attained a higher temperature than the other, and the difference was found to vary with the temperature—the greater the temperature the greater the difference. It was also observed that the coated bulb thermometer was longer reaching its maximum, and was subject to greater variations, and more rapid fluctuations than the thermometer with the plain black glass bulb.

The following table deduced from observation showed the variation of the differences with the increase of temperature, and prove clearly that the ordinary black glass bulb thermometer is not a reliable means of measuring solar radiation :

Black Glass Bulb.	Coated Glass Bulb.	Correction to be added to Black Glass Bulb.
Deg.	Deg.	Deg.
70	77·3	7·3
75	84·4	9·4
80	91·0	11·0
85	96·6	11·6
90	102·0	12·0
95	107·7	12·7
100	113·5	13·5
105	118·8	13·8
110	124·1	14·1
115	129·3	14·3
120	134·6	14·6
125	140·0	15·0
130	145·2	15·2
135	150·5	15·5
140	155·7	15·7

These results are exactly what we should expect if we accept Professor Tyndall's statement with respect to the diathermancy of black glass. The greatest heat rays belong to the invisible part of the spectrum, just beyond the least refrangible or red end; these rays are known to traverse substances perfectly opaque to all visible rays,* and would therefore pass through the black glass without absorption, be

* Indeed, when every trace of visible rays is sifted out from sunlight, the heat rays collected to a focus can be made to melt platinum—not a trace of light being sensible to the eye until the platinum becomes heated.

reflected back from the surface of the mercury, and lost, while the coating of the blackened bulb being nearly or quite opaque to all rays, the whole heat falling on the bulb becomes rapidly absorbed.

The polished surface exhibited by the black glass bulb too, must reflect many rays which would be absorbed by the dead surface of the blackened bulb, and further, the coated bulb would radiate heat very rapidly as compared with the polished glass surface, and give rise to variations due to the interposition of visible or invisible aqueous vapour in the atmosphere, which the plain glass bulb would be insensible to.

In the numerous observations made with these thermometers, many cases occurred in which the differences already given would not represent the actual observed differences—in some of which there could be no doubt the more rapid radiation of the blackened bulb during the drifting of thin filmy clouds across the sun was the cause of this, and I am inclined to attribute all such differences to the absorption of heat rays by aqueous vapour in the atmosphere, the more sensitive blackened bulb indicating the loss, while the black glass, with its badly radiating surface, remains insensible to such variations. In these fluctuations the lowest temperatures indicated by the coated bulb, were never so low as the highest shown by the plain black glass bulb.

Last December, in a communication I received from Mr. Todd, the director of the Adelaide Observatory, he makes the following remarks :—

"I recently had occasion to substitute a fresh solar thermometer for the one that had been in use for several years. They were both Negretti and Zambra's make, having black glass bulbs, and enclosed in vacuum tubes—the only difference being that the new one had a smaller bulb, and was enclosed in a smaller bulb. They were both compared with Greenwich standards, and had no appreciable error. They also both read exactly alike in the shade, or in hot water up to limits of scales. Yet, in the sun, the old one reads often 10° or 12° higher than the other, according to the intensity of solar radiation. How is this to be accounted for? It is a rather interesting question, because solar radiation observations are no longer comparable if the instruments differ, and I have for a long time noticed, with surprise, that yours and Sydney's observations are much lower than mine, which I have hitherto attributed to our much drier and consequently more heat transparent atmo-

sphere. But here are two first class instruments, of the same maker, made on same principle—reading in shade, &c., alike ; placed side by side, under precisely similar circumstances, differing 10° or 12° in their indications of solar radiation. I have seven or eight of these instruments in store, and I intend to try them all,—I will let you know the result, and in the meantime should be glad to have your opinion as to cause. Is it that the one reading the higher is in a more perfect vacuum, or the black glass different, one less absorbent than the other, or may the smaller outer bulb have anything to do with it ?"

From inquiry, I find Mr. Todd formerly used a thermometer with a blackened bulb, hence the higher solar radiation obtained in Adelaide, and the apparently low temperature in Melbourne and Sydney.

The differences between his new black glass bulb thermometers must, I think, depend on the different diathermancy of the glass of the bulbs, for if black glass is not opaque to heat rays, the thinner the glass the more diathermanous it must be, and it will be interesting to learn if coating these bulbs will render their indications similar or more comparable.

The highest temperatures in the sun published in the meteorological reports of the Melbourne Observatory up till the 1st of January 1868, have all been obtained from the ordinary black glass bulb thermometer, and do not therefore represent the true temperatures of the greatest solar radiation. The table first given furnishes an approximate correction, which, when applied, brings up the temperatures to what they would have been if measured by a blackened bulb thermometer—and I here append the maximum solar radiation for each year since 1860, as observed with the black glass bulb, as well as the true temperatures obtained by applying the correction :—

..	Black Glass Bulb.	Correction.	Coated Bulb.
1860	136·8	15·4	152·2
1861	129	15·1	144·1
1862	144·3	15·7	160
1863	133	15·3	148·3
1864	124	14·8	138·8
1865	126·1	15·1	141·2
1866	130·8	15·3	146·1
1867	131	15·3	146·3
(?) 1868	127·4	15·2	142·6